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Rate of Solution of N_2 in Liquid N_2O_4

DECEMBER 1966

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Prepared for BALLISTIC SYSTEMS AND SPACE SYSTEMS DIVISIONS
AIR FORCE SYSTEMS COMMAND
LOS ANGELES AIR FORCE STATION
Los Angeles, California

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FOREWORD

This report is published by the Aerospace Corporation, El Segundo, California, under Air Force Contract No. AF 04(695)-1001.

This report, which documents research carried out from 11 May 1966 through 23 November 1966, was submitted to Capt. John T. Allton, SSTRT, on 23 December 1966 for review and approval.

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Approved

R. A. Hartunian

R. A. Hartunian, Acting Director
Aerodynamics and Propulsion Research Laboratory

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

John T. Allton

John T. Allton, Capt., USAF
Space Systems Division
Air Force Systems Command

ABSTRACT

The rate of solution of N_2 in liquid N_2O_4 was measured in terms of the change of pressure with time at 5.1 and 7.6% ullage at 20°C and at 6.6% ullage at 0°C. The pressure decay was slower with increasing ullage and increasing temperature because of the relative masses of gas and liquid and the diffusional barrier near the interphase both in the gas and in the liquid. The rate of solution follows first-order reversible reaction rate after 40 min.

I. INTRODUCTION

The rates of solution of pressurization gases in liquid N_2O_4 are important in maintaining propellant tank pressures in several gas pressurized propulsion systems. Because N_2 is one of the most commonly used pressurization gases, an investigation on the rate of solution of N_2 in liquid N_2O_4 was undertaken.

The rate of solution of N_2 in liquid N_2O_4 was measured at 5.1 and 7.6% ullage at 20°C to observe the effect of ullage on the pressure decay. In addition, the rate at 0°C and 6.6% ullage was measured to obtain the effect of temperature on the pressure decay.

II. APPARATUS

The main apparatus used in this investigation was the gas solubility apparatus described in Ref. 1. Two new components were specially designed to contain N_2O_4 in a constant volume when the pressure is measured. The first component was the cylindrical container, which has a capacity of 97 ml. Its dimensions are 40-mm diam and 95-mm high, which approximates the scaled-down dimensions of a typical propellant tank. The second component was a connector that has a small, 8-mm long, levelling manometer and a three-way stopcock, both made of pyrex, 2-mm diam. The connector was fitted on the container with a ball and socket joint sealed with a Teflon O-ring. The connector joined the container to the main apparatus either directly, to admit gas, or indirectly by the leveling manometer to measure pressure. The mercury was maintained at a constant level in the manometer by adjusting the pressure in the main apparatus. The volumes of the connector and the container were calibrated by using mercury and water, respectively.

III. EXPERIMENTAL PROCEDURE

The experimental procedure for measuring the rate of solution was as follows. The connector and the container were assembled, evacuated, and weighed on an analytical balance to obtain the tare weight. The desired amount of commercially available N_2O_4 of 99.5% purity was purified and distilled into the container as described in Ref. 2. The container was weighed again to determine the amount of N_2O_4; it was connected to the main apparatus and then placed into a thermostated bath. The solubility apparatus was first evacuated, then pressurized with N_2. The two-way stopcock above the container was opened to allow pressurization of the liquid N_2O_4 by N_2 to the desired initial pressure. Then, the three-way stopcock was turned immediately so that it was closed to the solubility apparatus and opened to the small leveling manometer. The time-vs-pressure readings were taken at suitable intervals. The pressure readings were obtained by leveling the mercury in the small manometer and observing, at the same time, the difference in height of the Hg levels in the large manometer of the main apparatus. The pressure readings were taken every 10 to 15 min for the first hour and every 30 min for the subsequent 3 or 4 h. At the end of a run, the N_2O_4 was stirred vigorously for about 10 min; then the final pressure reading corresponding to infinite time was observed.

The ullage consisted of the volume above the liquid and the volumes of stopcocks and connecting tubes. The ullage was kept constant during each experiment by adjusting the Hg levels in the small manometer.

IV. RESULTS AND CONCLUSIONS

The pressure decay or the rate of solution of N_2 in liquid N_2O_4 was obtained from the resulting data. The results for the rate of solution of N_2 in liquid N_2O_4 for 5.1 and 7.6% ullage at 20°C are presented in Fig. 1, which shows the effect of ullage on the pressure decay. The results at 0°C and 6.6% ullage presented in the same figure show the effect of temperature. It was found that the greater ullage the slower the pressure decay and that the lower temperature the faster the pressure decay. Because the partial pressure of gaseous $(NO_2 + N_2O_4)$ is smaller at lower temperatures, it presents a lower gas-phase barrier for the solution of N_2 in liquid.

The pressure decay does not fit a reasonable reaction rate, although it appears to follow a first-order reversible reaction rate after 40 min. It is believed that the rate is both gas- and liquid-phase diffusion controlled. The experimental results substantiate that the gas-phase concentration gradient is indeed diffusion controlled; otherwise, the rate would not have increased at lower temperatures. The liquid-phase concentration barrier is known to retard the rate of solution in numerous liquids, and it is unlikely that N_2O_4 is an exception in this case.

The technique followed in these experiments was intended to assess the rate of solution with practical applications in mind. However, the results do not substantiate quantitatively a full theoretical application of solution rate. An actual tank containing much larger quantities of N_2 and N_2O_4 would present a slower pressure decay, but the presence of larger degrees of convection in the liquid and gaseous phases and the temperature gradients, as well as mechanical disturbances, would accelerate the pressure decay.

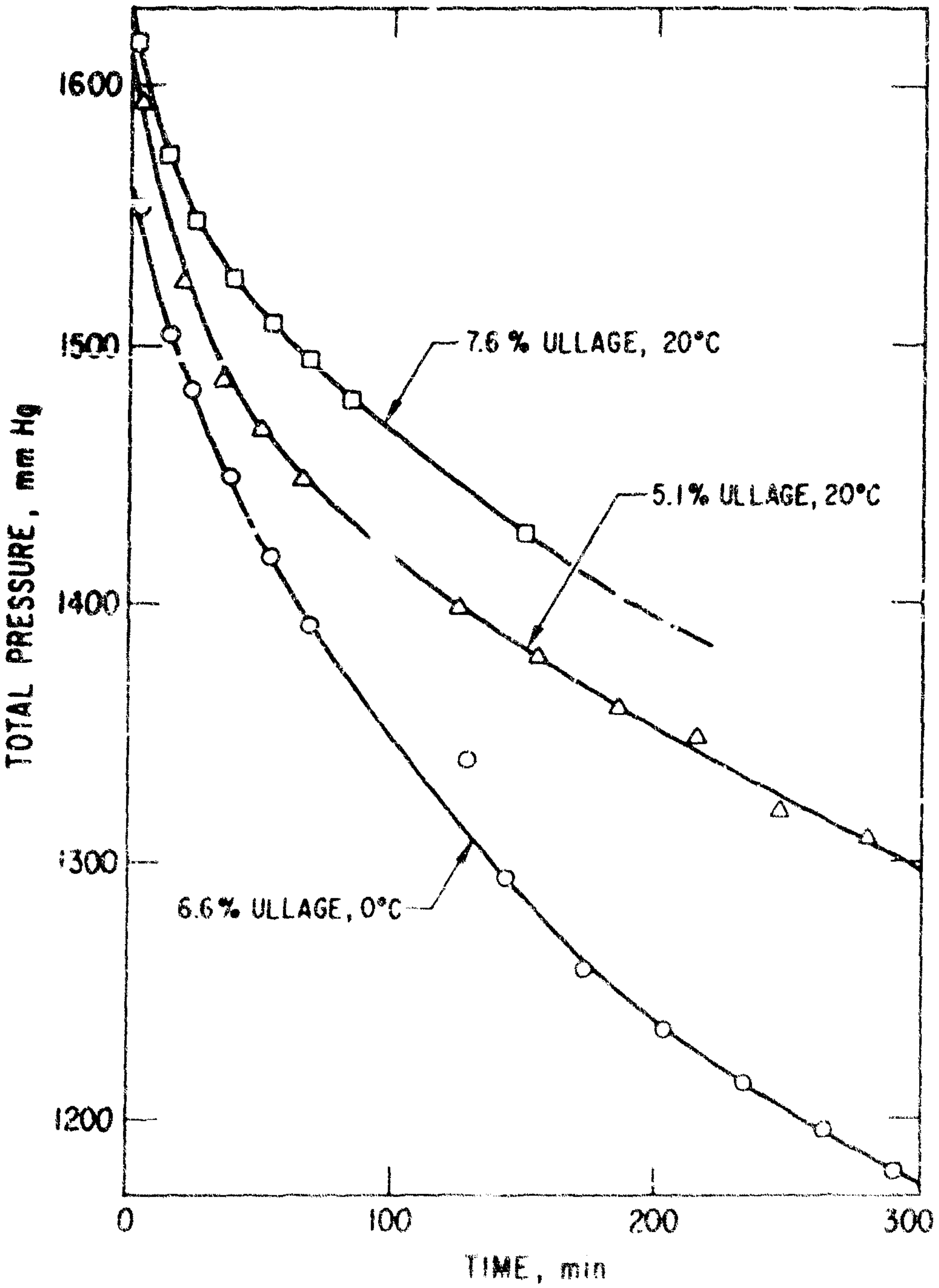

Fig. 1. Rate of Solution of N_2 in Liquid N_2O_4

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14. KEY WORDS

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